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HEUS - RS APPLICATIONS STUDY

FINAL REPORT - VOLUME II

D2-116262-2

Submitted To:

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AEROSPACE GROUP - SPACECRAFT DIVISION
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VOLUME II

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ABSTRACT

This document is Volume II of the final report of a High Energy Upper Stage - Restartable Solid (HEUS-RS) Applications Study, NASA Contract NAS 2-6518. The material in this document deals with launch program cost comparisons associated with meeting NASA mission model requirements with several different launch vehicle approaches.

KEY WORDS

Titan IIIB	NASA
Thor	Mission Model
Thorad	Recurring
Centaur	Nonrecurring
HEUS-RS	Cost

ABBREVIATIONS AND ACRONYMS

BII	Burner II
ΔV	Delta Velocity
ETR	Eastern Test Range
HEUS	High Energy Upper Stage
HEUS-RS	High Energy Upper Stage - Restartable Solid
ROM	Rough Order of Magnitude
TAT	Thrust Augmented THOR
WTR	Western Test Range
GFE	Government Furnished Equipment
GSE	Ground Support Equipment
AGE	Aerospace Ground Equipment

1.0 INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

This report presents the results of a Restartable High Energy Upper Stage Applications Study conducted for NASA under the technical direction of Jet Propulsion Laboratory, Contract NAS 2-6518. The objectives of the study were:

1. Analyze the mission performance capability of a restartable "High Energy Upper Stage" and determine the optimum restartable solid motor size that will provide NASA the most capability in meeting the mission class requirements when it is incorporated into the mission model.

2. Provide a conceptual configuration of a potentially high usage "High Energy Upper Stage" using a restartable solid motor (HEUS-RS).

3. Evaluate and compare the effect of restartable "High Energy Upper Stages" on launch program performance and cost.

Previous studies have shown significant payload performance gains when stop/re-start was incorporated into solid rocket motors. The most significant advantage of re-start capability is realized when used in the upper stage of two stage launch vehicles where the second burn of the upper stage can be used for apogee injection and/or the injection of more than one payload in different orbits. Appropriate application of this capability will preclude usage of more expensive multi-stage vehicles and result in total launch program cost savings.

The results of the study are contained in two volumes. Volume I, Technical, contains the launch program definition, restartable motor definition and upper stage configuration, performance analysis, and launch program evaluation. This document, Volume II, contains the cost data and the summary of Volume I.

This study originally consisted of six tasks. Task 1 through 5 were technical study tasks, task 6 was assigned for reporting only. As the study progressed, revisions were made to the task assignments, with some items deleted and Task 7 added.

1.2 SUMMARY

1.2.1 Background

Restartable solid motors have been studied by NASA and a feasibility demonstration motor was fired successfully in 1970. Preliminary analysis indicates the most significant advantage of restart capability is realized when used in an upper stage where the second motor burn can be used for apogee injection and/or the injection of more than one payload into different orbits.

The restartable solid motor fired by NASA incorporated high performance propellant containing a Beryllium additive to the propellant which increased the specific impulse.

This study considered only Aluminum added to the propellant mixture with a related I_s of 303 seconds.

1.2.2 Scope

This study was divided into seven tasks, six technical and one reporting. The work covered in each of the tasks is as follows.

Task 1 - Review the NASA mission model and separate it into four mission classes; Low Earth Orbit, Synchronous, Earth Escape, and Planetary Orbiter. Determine the number of launches for each mission class. These will be used for cost comparison in later tasks.

Task 2 - Perform preliminary performance trades for the mission. Mission classes and boosters listed in Task 1 were used to determine required single and multi-burn times and ΔV required to permit HEUS-RS sizing. Design "rubber" HEUS-RS stage configurations for each booster and mission class. Select optimum motor size and design an upper stage that has highest usage rate.

Task 3 - Perform a mission analysis using the HEUS-RS configuration and determine payload in orbit and trajectory data. (The HEUS-RS was applicable only to the low earth orbit missions.) Determine the total HEUS-RS launch program ROM cost. Determine a separate ROM cost for development and qualifications of HEUS-RS including launch vehicle and launch site integration.

Task 4 - Determine the total launch program ROM cost to perform the bulk of the mission flights generated in Task 1 mission model.

Task 5 - Compare the costs of Task 3 and 4.

Task 6 - Reporting, reviews, and documentation.

Task 7 - Determine the ability of the HEUS-RS/Burner II to perform and meet shuttle mission requirements.

During the course of the study, as results became known, changes to the original study outline were recommended and authorized. Some original study tasks were deleted and new tasks were added. These changes include the deletion of Air Force missions from Task 3, the replacement in Task 4 of the alternate launch concepts with launch vehicles and costs generated by Battelle Memorial Institute, the deletion of comparing the performance capability of Task 3 and 4 launch programs, and the addition of Task 7 HEUS/Burner II Shuttle Application.

A study flow diagram showing work performed under each task and the above mentioned study deletions and additions is shown in Figure 1.2-1.

HEUS STUDY

TASK #1 - LAUNCH PROGRAM DEFINITION

- o Mission Model
- o Performance
- o Booster Selection

TASK #2 - CONFIGURATION DEFINITION

- o ΔV Required
- o Burn Times
- o Stop/Starts
- o Rubber Configuration

TASK #3 - HEUS PROGRAM EVAL.

- o Select and Integrate HEUS Configuration
- o Performance/Mission Model
- o Cost-Recurring and Nonrecurring

OUT: o SESP Mission = P/L's

TASK #4 - ALTERNATE PROGRAM EVALUATION

OUT:
- o OSSA Assigned L/V
- o Multi P/L's
- o Multi Launches
- o Determine Costs

IN:
- o BMI Assigned L/V
- o BMI Costs

TASK #5 - PROGRAM COMPARISON

- o Costs - Nonrecurring and Recurring

OUT: o Performance/Mission

TASK #7 - SHUTTLE APPLICATION

IN:
- o Eval. Configuration
- o Stop/Starts
- o Δ V Requirements

TASK #6 - STUDY REPORT

- o Two Reviews
- o Monthly Letter
- o Final Pitch
- o Final Document

FIGURE 1.2-1

1.2.3 Summary

1.2.3.1 Launch Program Definition

The mission model provided at the beginning of the study was modified to reflect all available data on the missions listed. These modifications included launch vehicle assignment, revised mission data and deletion of missions where inadequate data, for the purposes of this study, were available.

Assignments of launch vehicles, where none were shown, were based on the NASA Launch Vehicle Estimating Factors books 1971 and 1972 (Reference Numbers 6 and 7). In cases where mission requirements could not be met with the vehicle assignment given, revised assignments were made.

The mission model includes low earth orbit, synchronous equatorial and escape missions. The study results show that the prime requirement for a restartable solid is the low earth orbit missions.

Evaluation of the mission model was accomplished with the HEUS stages in combination with the Thorad, Titan IIIB and Titan IIID. No appropriate applications were found for the HEUS with Delta or Centaur. The Delta and Centaur already offer a restart capability and the additional restart of HEUS provides no increased capability over a non-restartable solid motor.

1.2.3.2 Task 2 Summary

Payload capability was evaluated for three motor sizes, 3000, 5000 and 7000 pounds propellant, that evolved from preliminary sizing studies. HEUS configurations were developed for each motor size, and weight statements defined.

A mission model analysis was used to determine the best motor size up to 7000 pounds for the final HEUS configuration. The impact of the increased propellant weight in the HEUS was to allow the use of a smaller booster for a given mission. However, this impact was secondary compared to the fundamental impact of being able to shut down and restart the restartable solid motor.

Based on this analysis, coupled with the fact that the feasibility demonstration motor was in the 3000 pound size range, the baseline HEUS configuration of approximately 3000 pounds propellant was selected for the final phase of the study.

1.2.3.3 HEUS-RS Launch Program Evaluation

Launch vehicle performance for the HEUS configuration was determined on a general basis. Payload data for East, Polar and 100° inclination orbits with the restartable BE-15B2, TE-M-364-2 and TE-M-364-4 was developed. A general comparison of the relative performance of these configurations is shown in Figure 1.2.3.3-1.

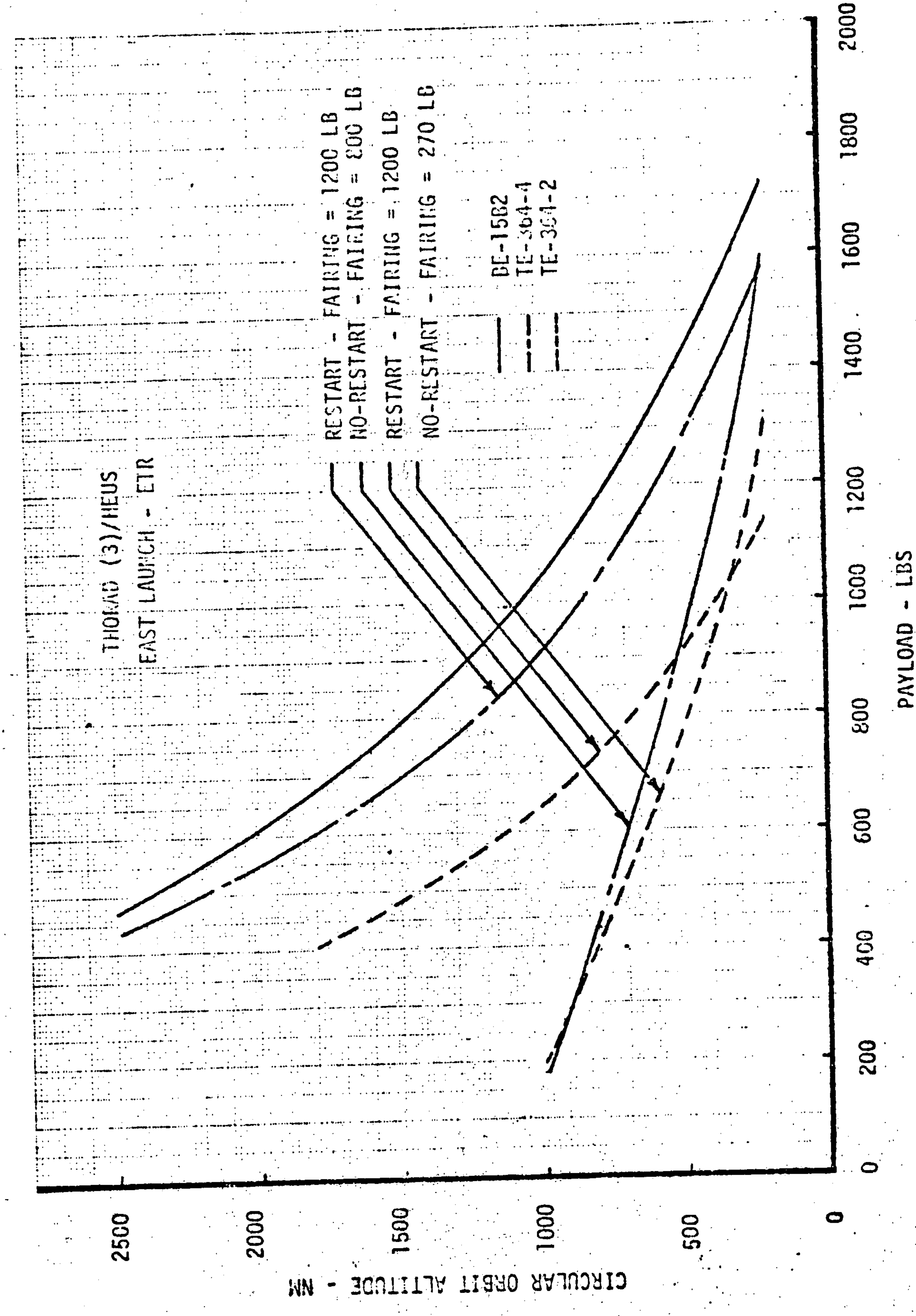

FIGURE 1.2.3.3-1

These data include the non-restartable TE-M-364-2 and TE-M-364-4 Burner II stages on a three strap-on Thorad. A significant performance increase can be realized with the restartable stages. The impact of this performance gain is not totally apparent in the mission model evaluation because program performance requirements naturally gravitate to the current launch vehicle capability.

The performance regime available with the HEUS would certainly attract mission assignments were it a part of the NASA launch vehicle stable.

The total HEUS-RS launch program cost was determined assuming the restartable motor was already fully qualified. The total mission model launch program cost, utilizing the Hercules BE 15B2 upper stage configuration where applicable, is estimated at slightly over 3 billion dollars.

The ROM cost for development and qualification of the new upper stage including the Hercules BE 15B2 motor, design and test, tooling, and in-house GSE is slightly over 7 million dollars. An additional 1.5 million dollars would be required to integrate the new upper stage on a second booster configuration. The GSE required for 4 launch pads at 2 sites (2 each at WTR and ETR) would amount to 2.2 million dollars. Average recurring cost for the HEUS-RS stage, including motor would be 790,000 dollars each.

1.2.3.4 Task 4 Summary

The total mission model launch program was priced, using applicable existing launch vehicles without the HEUS-RS capability. The total cost is estimated at 3.27 billion dollars. Launch vehicle assignments included standard Thorads, Delta, Titan, and Centaur. Substituting the "Straight 8" for the standard Thorad resulted in a total cost of approximately 3.39 billion dollars.

1.2.3.5 Task 5 Summary

Task 5 was a cost comparison of the HEUS-RS launch program costs developed in Task 3 and the cost using existing launch vehicles (Task 4). Table 1.2.3.5-1 shows the summary comparison between Task 4 assigned program costs and the program costs with incorporation of the HEUS-RS upper stage. Incorporation of the HEUS-RS where applicable results in a total program cost saving of approximately 316 million dollars (slightly over 9%).

1.2.3.6 HEUS/Burner II Shuttle Applications

The HEUS configurations provide an attractive capability for Space Shuttle interim tug. General performance data was developed to show the HEUS capability for various orbit attitudes and inclination changes. The HEUS configurations provide almost total coverage for the low earth orbit missions of the study mission model.

TOTAL PROGRAM COMPARISON

220 MISSIONS

17 YEAR PROGRAM

DOLLARS IN MILLIONS

ASSIGNED PROGRAM			**RESTART PROGRAM**
RECURRING HARDWARE	=	$2,107.4 M	$1,771.7 M
ANNUAL SUPPORT	=	1,279.6 M	1,291.6 M
TOTAL		$3,387.0 M	$3,063.3 M
SAVINGS WITH RESTART:			
RECURRING HARDWARE	=		$ 335.7 M
LESS ANNUAL SUPPORT	=		+12.0 M
LESS DEVELOPMENT AND INTEGRATION	=		+8.0 M
		NET SAVING =	$ 315.7 M
			≈9%

TABLE 1.2.3.5-1

1.2.4 Conclusions and Recommendations

The conclusions and recommendations resulting from this study are as follows:

1. HEUS configurations have a significant impact on low earth orbit missions.

2. Advantages of restartable solids not completely demonstrated by analysis of this particular mission model, since the model was based on existing launch capabilities.

3. Incorporation of quench-restart capability in an existing motor of the 2000 to 2500 pound propellant weight class provides nearly the same low earth orbit capability as the 3000 pound propellant HEUS motor and should provide a significant reduction in development cost.

4. HEUS could provide complete coverage of the low earth orbit mission with small changes to mission requirements.

5. Larger propellant weight configurations or tandem configurations would be required to provide synchronous equatorial capability in the shuttle applications.

6. Additional study is required to determine HEUS compatibility with the shuttle.

7. Development cost for the HEUS-RS is amortized in the first year of use. Average annual savings, shown on Figure 1.2.4-1, are approximately $18.5 million per year for the study mission model.

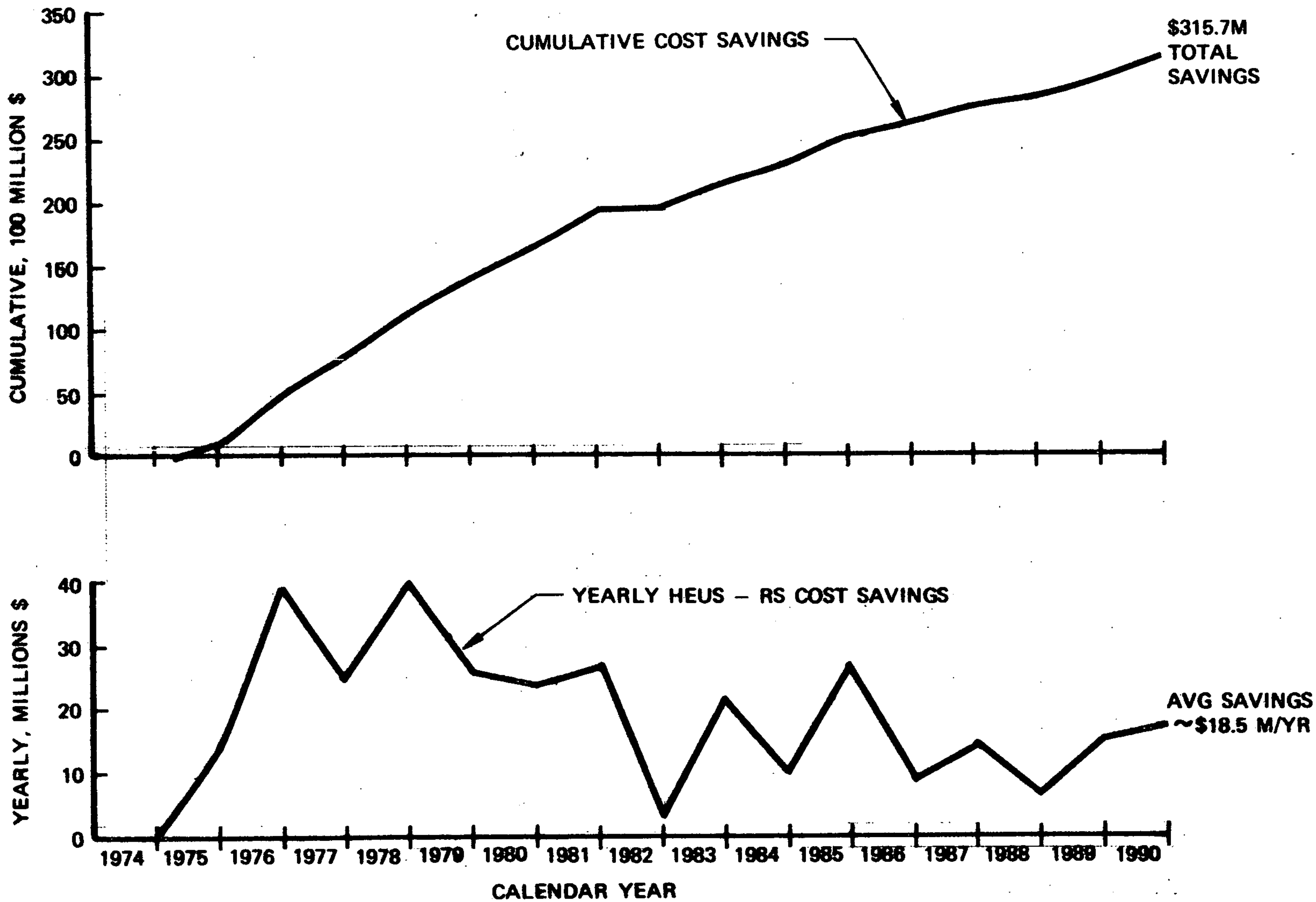

FIGURE 1.2.4-1 HEUS – RS COST SAVING

2.0 COSTING GROUND RULES

The following costing ground rules were used to generate the cost data in this report.

a. All costs in 1972 dollars.

b. The mission model supplied by JPL was used, but Scout missions were deleted.

c. Launch vehicle assignments were upgraded where the assigned vehicle performance was inadequate for the stated mission requirements.

d. Launch vehicles were assigned for mission model omissions.

e. The HEUS-RS motors were included in hardware recurring costs.

f. Upper stage motor costs are based upon supplier quotes and requirements for 5 to 8 motors per year.

g. Upper stage development costs were derived from the Burner II/Improved Centaur Integration Study.

h. Upper stage hardware costs are the average of 100 units, with a learning curve applied.

i. Booster stage hardware costs were taken from Document BMI-NLVP-TR-70-1 Table D-1 and 1968 AACB data.

j. Booster launch support costs were derived from Document BMI-NLVP-TR-70-1 Table D2 and Panel AACB 1968, (Annual Costs).

k. Both ETR and WTR will be used as launch sites. Two launch pads at each site.

l. Launch site facilities, brick and mortar and utilities have not been costed as part of this estimate.

m. AGE for the Booster stages, i.e., Titan, Atlas/Centaur, etc., is assumed to be in inventory, therefore, not costed. (GFE)

n. AGE cost for the HEUS-RS upper stage has been delineated on the upper stage comparison sheet.

o. Hardware and support costs were developed by incorporating the various mixes of Boosters and numbers of launches in the mission models.

p. HEUS-RS support crews assumed to be in residence at launch pads.

3.0 COSTS

This section contains the estimated costs in accordance with the specific ground rules and the contract statement of work. The vehicle assignments to the mission model were obtained from the performance evaluations, which are discussed in detail in Volume I of this report. The mission model was subjected to five cost evaluations, as follows:

a. Using the assigned launch vehicle (no HEUS-RS). Where the assigned vehicle was Thorad, the standard version was used.

b. Same as a., but substituting the "Straight 8" Thorad for the standard version.

c. Substituting the HEUS-RS stage where appropriate, based on vehicle mission performance. The Hercules BE15B2 motor was used in the new HEUS-RS stage. Standard Thorad.

d. Same as c., but with the "Straight 8" Thorad.

e. Same as d., but substituting a restartable verion of the Thiokol TE-M-364-4 as the upper stage instead of the Hercules BE15B2.

3.1 BURNER II/RE-START COSTS

The nonrecurring and recurring costs for the Burner II with restartable solid motor are summarized on Table 3.1-1. Burner II hardware costs were derived from previous studies where a new solid rocket motor and booster were used. As can be seen on Table 3.1-1, once the new stage has been developed and integrated into a launch vehicle, integration with other launch vehicles adds little to the cost.

3.1.1 Motor Costs

Table 3.1-1 shows cost data for two restartable motors; the Hercules BE-15-B2 and the Thiokol TE-M-364-4, with quench/restart incorporated.

3.1.1.1 Hercules Motor

The Hercules BE-15-B2 motor with water quench and restart capability is based on the motor presently under prototype development. The nonrecurring development and qualification program includes 3 development and 4 qualification motors, plus engineering analysis, and tooling. Development could begin in July 1973. The recurring price of $200,000 per motor is based on six to eight motor deliveries per year.

	BURNER II/BE-15-B2		BURNER II/-4 R/S	
NONRECURRING				
MOTOR	$3,900		$2,750	
DESIGN AND TEST	2,780		2,780	
GSE *	310		310	
TOOLING	140		140	
IS	$7,130	FIRST BOOSTER CONFIGURATION	$5,980	FIRST BOOSTER CONFIGURATION
	$1,500	SECOND BOOSTER CONFIGURATION	$1,500	SECOND BOOSTER CONFIGURATION
	$8,630		$7,480	
RECURRING				
SPARES	$ 38		$ 38	
AVE	552		552	
MOTOR	200		160	
AVERAGE COST	$ 790		$ 750	
GSE **	$2,200		$2,200	

* GSE In-House.
** GSE for 4 Launch Pads.

BURNER II/RESTART COSTS

TABLE 3.1-1

3.1.1.2 Thiokol Motor

The Thiokol approach would incorporate a quench and restart system in the TE-M-364-4 motor. This basic 364-4 motor is already qualified and in flight status. Development and qualification of the quench/restart version of the motor would include small motor testing (5 inch and 8 inch), subscale testing using the TE-M-604 motor, four full-scale development tests, and five qualification tests. The program would take approximately 20 - 24 months through completion of qualification.

Recurring cost of $160,000 each is based on a delivery rate of five to six motors per year.

3.2 SPECIFIC TASKS

The following tables provide the data specifically called out in the statement of work. In each instance, the statement of work is restated and the data is provided.

3.2.1 HEUS-RS Launch Program Evaluation

Tables 3.2.1-1 through 3.2.1-4 provide the data specified in Task 3 of the statement of work. Table 3.2.1-1 provides the mission model costs utilizing the BE-15-B2 motor where applicable. The Thorad launch vehicle in this launch program is the standard version.

Table 3.2.1-2 is the same as 3.2.1-1, but with the "Straight 8" Thorad in place of the standard Thorad.

Table 3.2.1-3 provides the nonrecurring and recurring cost data for the upper stage assuming the motor is already qualified. The nonrecurring cost shows no difference in stage development between the Hercules BE-15-B2 motor version or the Thiokol TE-M-364-4 motor version. A more detailed analysis might show the stage development for the 364-4 motor configuration to be less expensive, but no significant differences appeared in this analysis.

The recurring costs in Table 3.2.1-3 show the motor comparison of $200,000 for the BE-15-B2 versus $160,000 for the TE-M-364-4.

Table 3.2.1-4 summarizes the nonrecurring and recurring costs for the Burner II/restart (HEUS-RS) stage with the BE-15-B2 motor included. Launch vehicle and launch site integration are included. Although similar data does not appear on the table for the TE-M-364-4/RS version, the comparative cost summary can be easily obtained from the following:

	BE-15-B2	TE-M-364-4
Nonrecurring	$3,900,000	$2,750,000
Recurring	$ 200,000	$ 160,000

TASK #3 HEUS-RS LAUNCH PROGRAM EVALUATION

The following capability of the Restartable solid when conceptually integrated into an upper stage (HEUS-RS) vehicle (Task #2) shall be determined for the missions defined in Task #1.

Dollars in Thousands

TASK #3 c) A total HEUS-RS launch program ROM cost shall be determined assuming the restartable motor is developed and fully qualified. Integration nonrecurring and recurring costs (ROM) shall be estimated based on ground rules similar to those generated for Burner II/Burner IIA. Launch Vehicle and launch support costs shall be as shown in available Launch Vehicle Panel AACB 1968 data or as provided by NASA.

A mission model utilizing the Burner II/BE-15-B2, Standard Thorads, Atlas/Centaur, and Titan Boosters was constructed, for given NASA Space missions. The model was costed delineating nonrecurring costs for the Burner II/BE-15-B2 stage and recurring costs for the mission model.

COST

Nonrecurring	GSE *	Recurring: Hardware	Recurring: Launch Support	Total Recurring	Total Mission Model Utilizing Standard Thorads and BE-15-B2
$4,730	$2,200	$1,734,452	$1,289,780 **	$3,024,232	$3,031,162

* GSE for 4 launch pads at 2 sites.

** Launch support costs are based on annual launch services costs, as shown on Table 3.2.3-6. Eighty-eight launches utilize the HEUS-RS at a launch support cost of $100,000 each, resulting in an increase of $8,800,000 over the basic mission model without HEUS-RS.

TABLE 3.2.1-1

TASK #3 HEUS-RS LAUNCH PROGRAM EVALUATION

The following capability of the Restartable solid when conceptually integrated into an upper stage (HEUS-RS) vehicle (Task #2) shall be determined for the missions defined in Task #1.

Dollars in Thousands

Task #3 c) A total HEUS-RS launch program ROM cost shall be determined assuming the restartable motor is developed and fully qualified. Integration nonrecurring and recurring costs (ROM) shall be estimated based on ground rules similar to those generated for Burner II/Burner IIA. Launch vehicle and launch support costs shall be as shown in available Launch Vehicle Panel AACB 1968 data or as provided by NASA.

A mission model utilizing the Burner II/BE-15-B2, Straight 8 Thorads, Atlas/Centaur, and Titan Boosters was constructed, for given NASA Space Missions. The model was costed delineating nonrecurring costs for the Burner II/BE-15-B2 stage and recurring costs for the mission mode.

COST

		Recurring			
Nonrecurring	GSE *	Hardware	Launch Support	Total Recurring	Total Mission Model Utilizing Standard Thorads and BE-15-B2
$4,730	$2,200	$1,771,740	$1,291,633**	$3,063,373	$3,070,303

* GSE for 4 launch pads at 2 sites.

** Launch support costs include 104 launches utilizing the HEUS-RS. (See Table 3.2.3-7).

TABLE 3.2.1-2

TASK 3c

UPPER STAGE COMPARISON
ASSUME RESTARTABLE MOTOR DEVELOPED AND QUALIFIED

Dollars in Thousands

	Burner II/BE-15-B2 Hercules		Burner II/-4 R-S Thiokol	
Nonrecurring:				
Design and Test	$2,780		$2,780	
GSE *	310		310	
Tooling	140		140	
	$3,230	First Booster Configuration	$3,230	First Booster Configuration
	$1,500	Second Booster Configuration	$1,500	Second Booster Configuration
	$4,730		$4,730	
Recurring:				
Spares	$ 38		$ 38	
AVE	552		552	
Motor	200		160	
Average Cost	$ 790		$ 750	
GSE **	$2,200		$2,200	

* GSE In-House
** GSE for 4 launch pads at 2 sites.

TABLE 3.2.1-3

TASK #3 HEUS-RS LAUNCH PROGRAM EVALUATION

The following capability of the Restartable solid when conceptually integrated into an upper stage (HEUS-RS) vehicle (Task #2) shall be determined for the missions defined in Task #1.

Dollars in Thousands

TASK #3 d) A separate ROM cost for development and qualification of the HEUS-RS including launch vehicle and launch site integration shall be estimated. Recurring ROM cost of the HEUS-RS will be estimated based on potential usage rate per year.

The mission model utilizing Standard Thorads and BE-15-B2 requires 94 Burner II/BE-15-B2 stages. This averages 5.5 upper stages per year for the duration of the mission model. The nonrecurring costs for Burner II/BE-15-B2 stage include solid motor development. The recurring cost is the average cost on 94 units.

COST

Nonrecurring	GSE *	Recurring (Average)
$8,630	$2,200	$790

* GSE for 4 launch pads at 2 sites.

TABLE 3.2.1-4

3.2.2 Alternate Launch Program Costs

The "alternate" launch program uses current launch vehicle assignments for the mission model with no restartable solid stage considered. Where no current launch vehicle assignment was available for a particular mission, an assignment was made based on mission performance requirements. Where the currently assigned vehicle was unable to meet mission requirements, another vehicle was substituted. A summary of the costs is as follows:

	Recurring (Millions)		Total Cost
	Hardware	Support	(Millions)
Basic Mission Model	1,990.7	1,279.6	3,270.3
Basic Mission Model Utilizing Thorad "Straight 8"	2,107.4	1,279.6	3,387.0

3.2.3 Program Comparisons

The recurring hardware for five launch programs (launch vehicle assignments) was costed. The costs were separated into three (3) classes of missions. HEUS-RS stages were incorporated into the low earth orbit class of missions only. Table 3.2.3-1 contains a breakdown of recurring hardware costs.

Total launch program costs for the five launch programs is contained on Table 3.2.3-2.

The cost of development and qualification of the HEUS-RS and the cost of integrating the HEUS-RS to the second booster configuration is contained on Table 3.2.3-3.

The launch support costs including sustaining engineering and pad maintenance are shown on Tables 3.2.3-4 through 3.2.3-8 for the five launch programs.

NASA MISSION MODEL HARDWARE COSTS

Dollars in Thousands

	Recurring			
	Low Earth Orbit Missions	Planetary and Escape Missions	Synchronous Earth Orbit and High Orbit	Total Cost
Basic NASA Mission Model Utilizing Standard Thorads	$ 914,357	$ 369,170	$ 707,191	$1,990,718
Basic NASA Mission Utilizing Thorad Straight 8 [1]	1,031,083	369,170	707,191	2,107,444
Utilization Standard Thorads and BE-15-B2	658,091	369,170	707,191	1,734,452
Utilization Straight 8 Thorads and BE-15-B2 [1]	695,379	369,170	707,191	1,771,740
Utilization Straight 8 Thorads and TE-M-364-4	703,249	369,170	707,191	1,779,610

[1] The mission model launch vehicle assignments included standard Thorads, Titan, Delta, and Centaur. Variations shown substitute "Straight 8" for standard Thorad.

TABLE 3.2.3-1

NASA MISSION MODEL COSTS

Dollars in Millions

	Recurring		
	Hardware	Support *	Total Cost
Basic NASA Mission Model	$1,990.7	$1,279.6	$3,270.3
Basic NASA Mission Model Utilizing Thorad Straight 8	2,107.4	1,279.6	3,387.0
Utilization Standard Thorads and BE-15-B2	1,734.4	1,289.8	3,024.2
Utilization Straight 8 Thorads and BE-15-B2	1,771.7	1,291.6	3,063.3
Utilization Straight 8 Thorads and TE-M-364-4	1,779.6	1,291.6	3,071.2

* Launch support costs are based on annual launch services costs. Where restartable solid motor upper stages are used, support costs reflect increases over the basic mission model support costs reflecting the costs associated with launching the HEUS-RS (See Tables 3.2.3-6 and 3.2.3-7)

TABLE 3.2.3-2

HEUS-RS MOTOR AND STAGE COSTS

Dollars in Thousands

	Burner II/BE-15-B2 Hercules		Burner II/-4 R-s Thiokol	
Nonrecurring				
Motor	$ 3,900		$ 2,750	
Design and Test	2,780		2,780	
GSE *	310		310	
Tooling	140		140	
	$ 7,130	First Booster Configuration	$ 5,980	First Booster Configuration
	$ 1,500	Second Booster Configuration	$ 1,500	Second Booster Configuration
	$ 8,630		$ 7,480	
Recurring				
Spares	$ 38		$ 38	
AVE	552		552	
Motor	200		160	
Average Cost	$ 790		$ 750	
GSE **	$ 2,200		$ 2,200	

* GSE In-House.
** GSE for 4 launch pads @ 2 sites.

TABLE 3.2.3-3

LAUNCH SUPPORT COSTS
(Dollars in Thousands)

NASA MISSION MODEL

STANDARD THORADS

Centaur	102 Launches	17 Years @ $18,000	$306,000
Delta	98 Launches	17 Years @ $17,000	289,000
Atlas	57 Launches	17 Years @ $10,000	170,000
Titan	57 Launches	17 Years @ $20,000	340,000
		1969	$1,105,000
		Escalated to 1972	$1,279,590

Reference: BMI-NLYP-TR-70-1, Table D-2

Table 3.2.3-4

LAUNCH SUPPORT COSTS
(Dollars in Thousands)

NASA MISSION MODEL

STRAIGHT 8 THORADS

Centaur	102 Launches	17 Years @ $18,000	$306,000
Delta	98 Launches	17 Years @ $17,000	289,000
Atlas	57 Launches	17 Years @ $10,000	170,000
Titan	57 Launches	17 Years @ $20,000	340,000
			$1,105,000
		Escalated to 1972	$1,279,590

Reference: BMI-NLYP-TR-70-1, Table D-2

Table 3.2.3-5

LAUNCH SUPPORT COSTS

Dollars in Thousands

NASA MISSION MODEL
UTILIZING STANDARD THORADS AND BE-15B2

Centaur	68 Launches	17 Years @ $18,000	$306,000
Delta	96 Launches	17 Years @ $17,000	289,000
Atlas	23 Launches	17 Years @ $10,000	170,000
Titan	93 Launches	17 Years @ $20,000	340,000
BE 15 B2	45 Launches on TAT's @ $100		4,500
BE 15 B2	43 Launches on Titans @ $100		4,300
		1969	$1,113,800
		Escalated to 1972	$1,289,780

REF.: BMI-NLYP-TR-70-1 Table D-2

BE 15 B2 Support costs are a delta increase to the annual support costs shown BMI-NLYP-TR-70-1

NOTE: Launch Support costs are fixed annual costs for Centaur, Delta, Atlas, and Titan and are independent of the number of launches. Each time the HEUS-RS is launched (45 on TAT and 43 on Titan), the incremental $100,000 launch support cost is added to the total as shown here and on Tables 3.2.3-7, and 3.2.3-8.

Table 3.2.3-6

NASA MISSION MODEL

UTILIZING STRAIGHT 8 THORADS AND BE-15 B2

Centaur	69 Launches	17 Years @ $18,000	$306,000
Delta	99 Launches	17 Years @ $17,000	289,000
Atlas	23 Launches	17 Years @ $10,000	170,000
Titan	90 Launches	17 Years @ $20,000	340,000
BE-15 B2	64 Launches on TAT's @ $100		6,400
BE-15 B2	40 Launches on Titans @ $100		4,000
		1969	$1,115,400
		Escalated to 1972	$1,291,633

BE-15 B2 Support costs are a delta increase to the annual support costs shown BMI-NLYP-TR-70-1

NOTE: Launch Support costs are fixed annual costs for Centaur, Delta, Atlas, and Titan, and are independent of the number of launches. Each time the HEUS-RS is launched (64on TAT and 40 on Titan), the incremental $100,000 launch support cost is added to the total as shown here and on Tables 3.2.3-6, and 3.2.3-8.

Table 3.2.3-7

NASA MISSION MODEL

UTILIZING STRAIGHT 8 THORADS AND TE-M-364-4

Centaur	69 Launches	17 Years @ $18,000	$306,000
Delta	101 Launches	17 Years @ $17,000	289,000
Atlas	23 Launches	17 Years @ $10,000	170,000
Titan	87 Launches	17 Years @ $20,000	340,000
TE-M-364-4	64 Launches on TAT's @ $100		6,400
TE-M-364-4	40 Launches on Titans @ $100		4,000
		1969	$1,115,400
		Escalated to 1972	$1,291,633

TE-M-364-4 Support costs are a delta increase to the annual support costs shown BMI-NLYP-TR-70-1

NOTE: Launch Support costs are fixed annual costs for Centaur, Delta, Atlas, and Titan and are independent of the number of launches. Each time the HEUS-RS is launched (64 on TAT and 40 on Titan), the incremental $100,000 launch support cost is added to the total as shown here and on Tables 3.2.3-6 and 3.2.3-7.

Table 3.2.3-8

4.0 REFERENCES

1. 2-1109-3600-570, HEUS Study Status Report for October 1971, dated 4 November 1971.

2. 2-1109-3600-655, HEUS Study Status Report for November 1971, dated 14 December 1971.

3. 2-1109-3600-153, HEUS Study Status Report for February 1972, dated 6 March 1972.

4. 2-1109-3600-238, HEUS Study Status Report for February 1972, dated 10 April 1972.

5. Report Number H250-12-6-7, July 1970, Final Report, Phase II, High Energy Upper Stage Motor Program. Volume I through IV, prepared by Hercules , Incorporated, Wilmington, Delaware.

6. NHB 7100.5 NASA Launch Vehicle Estimating Factors Handbook, January 1971 Edition.

7. NHB 7100.5 NASA Launch Vehicle Estimating Factor Handbook, January 1972 Edition.